REVIEWS.

SOME RECENT PAPERS ON THE INFLUENCE OF GRANITIC INTRUSIONS UPON THE DEVELOPMENT OF CRYSTALLINE SCHISTS.

MICHEL-LÉVY: *Contribution à l'étude du Granite de Flamanville et des Granites Français en général.* Bull. des Services de la carte géol. de la France, No. 36. Paris, 1893, pp. 41.

L. DUPARC and L. MRAZEC: *Nouvelles Recherches sur le massif du Mont-Blanc.* Archives des Sciences Physiques et Naturelles. Tome XXXIV, 1895, pp. 39.

L. DUPARC: *Le Mont-Blanc au point de vue géologique et pétrographique. Ibid.* 1896, pp. 8.

J. VALLOT and L. DUPARC: *Sur un Synclinal schisteux ancien formant le coeur du massif du Mont-Blanc.* Comptes Rendus des Séances de l'Académie des Sciences. Paris, Mars 1896, pp. 3.

J. HORNE and E. GREENLY: *On Foliated Granites and their relation to the Crystalline Schists in Eastern Sutherland.* Quarterly Journal of the Geological Society. London, Vol. LII, 1896.

A. SAUER: *Geologische Specialkarte des Grossherzogthums Baden.* Erläuterungen zu Blatt Gengenbach. Heidelberg, 1894, pp. 87.

A. SAUER: *Ibid.* Erläuterungen zu Blatt Oberwolfach-Schenkenzell. Heidelberg, 1895, pp. 76.

F. SCHALCH: *Ibid.* Erläuterungen zu Blatt Petersthal-Reichenbach. Heidelberg, 1895, pp. 82.

A. ANDREÆ and A. OSANN: *Ibid.* Erläuterungen zu Blatt Heidelberg. Heidelberg, 1896, pp. 60.

G. KLEMM: *Beitrage zur Kenntniss des krystallinen Grundgebirges im Spessart.* Abh. der Gross. Hessischen Geologischen Landesanstalt zu Darmstadt. 1895, pp. 87.

In one of the oldest and best known of the German universities there is delivered annually a very able and exhaustive course of lectures on petrography, in which no less than fourteen lectures are devoted to a presentation of our knowledge of the single rock, granite, but it is

nevertheless somewhat depressing to consider on how many important questions connected with this, the most common and ordinary of all the plutonic rocks, there are still grave differences of opinion among those justly considered as authorities. Thus all do not agree even as to the order of the crystallization of the constituents of the rock, some holding that there are two generations and others that there is but one, while again a marked difference of opinion exists concerning the effects produced by granite upon the rocks through which it is intruded.

As the result of a whole series of careful studies on various contact zones, chiefly in Germany, Austria, and Scandinavia, it is commonly believed in these countries that the granite magma, by its heat, pressure and escaping vapors, causes a recrystallization of the country rock, the process being one of diagenesis, the granite giving nothing to the rock through which it breaks, except in places, perhaps, a small amount of boracic acid.

In France, however, and everywhere within the French "sphere of influence" different opinions prevail, and it would actually appear from the studies made in these parts of Europe that the laws of nature changed upon crossing the political boundaries. Contact zones have been described by Barrois, Michel-Lévy, Delage, and other French petrographers, in which the country rock adjacent to the granite has become completely "granitized" by the transfusion of granitic material into it, and in a well-known paper by Michel-Lévy, which appeared in 1887,[1] he stated it as his belief that by this process gneisses, leptynites, dolomitic schists and amphibolites, indistinguishable from those of the Archaean, are produced, and that in fact the so-called primitive rocks have really originated in this way, by the intrusion of igneous rocks into clastic sediments, which sediments have undergone a profound metamorphosis with the addition of an immense mass of material, the process being essentially one of a metasomatosis.

In the first section of the Bulletin, whose title is given above, Michel-Lévy describes an additional contact zone of this kind occurring about the granite of Flamanville, which granite cuts shales, sandstones, and quartzites, chiefly of Silurian and Devonian Age. On approaching the granite the shales present successively the usual zones of the spotted clay slate, micaceous clay slate, and hornstone, but in the vicinity of the actual contact they are broken up, eaten into, and partially dis-

[1] Sur l'origine des terrains cristallins primitifs. Bull. Soc. Géol. de France, III 1887, 103.

solved by the granite, which holds many inclusions and also injects itself into the rock in narrow veins—*lit par lit*—along its plains of lamination or foliation, altering it intensely and at the same time giving to it a granitic character. In the second half of the Bulletin the author presents some observations on granites in general, more especially in relation to their contact effects, reaffirming and somewhat enlarging upon the views put forward by him in 1887. He holds that the conclusions arrived at by Rosenbusch and commonly held by petrographers, that feldspar is not usually produced in contact zones except in comparatively small amount by the diagenesis of the altered rock, and that there is no transfusion of granitic material into the invaded rock, although true of the individual contact zones investigated, are not true of contact zones in general, but that there is frequently developed immediately along the contact a zone in which an intimate admixture of the granitic material with that of the injected rock is a dominant characteristic. This admixture is brought about in part by the injection of the granite in thin layers—*lit par lit*—into the stratified rock parallel to its lamination, in part by a transfusion in some obscure way by means of mineralizing solutions of the elements of quartz and feldspar through the schists, causing these minerals to crystallize out through the substance of the altered rock, and in part by the actual solution of the injected rock in the granite magma. In this zone, which in ordinary granite intrusions is usually but a few yards in width, there can be found all the rocks characteristic of the great regions of crystalline schists—mica schists, granulites, gneisses, amphibolites, etc., formed by the action of the granite on the ordinary sedimentary strata of the earth's crust.

This zone, moreover, although often narrow as exposed, where the deeper seated parts of the "appareils granitiques" are laid bare to our study by the process of denudation, is found to become much wider and often of great stratigraphical importance. Barrois is cited as having found in Brittany cases where there has been an undoubted transformation of whole districts of Cambrian schists into gneiss by the process of "granitization" above referred to, it being possible to follow bands of quartzite which resist the general "feldspathization" from the margin of the area into parts of the district where the associated schists have been completely transformed into gneiss.

The work of Duparc and Mrazec, on the massiv of Mont Blanc is also cited as affording conclusive demonstration of similar transforma-

tion, while the gneissic zone about the granulite of the Saxon Granulitgebirge is cited as another case in point. It is believed that the granite magma first rises along lines of fracture in the crust. Its presence leads to a heating of the rock into which it is injected, and its intrusion is accompanied by a "*circulation intense*" of mineralizing fluids, probably rich in alkalis. These produce at first a transference of quartz from one part of the mass to another and the development of biotite, which is a marked feature in contact zones. Then follows "feldspathization," which commences by the development of little strings of quartz and feldspar following for the most part the schistosity of the invaded rock, and which grow in size until the whole mass of the schist is transformed into granite, the texture of the schist being broken down and its elements set in motion to form with the transfused material new combinations. The granitic magma or emanations thus slowly dissolve, alter or incorporate, whichever we may choose to call it, the wall rock, transforming it first into a gneiss, then into a gneissic granite, and finally into a granite. The original intrusion thus slowly enlarges its boundaries and increases its volume.

This process, we are told, is at work wherever granitic magmas come in contact with clastic rocks in the deeper parts of the earth's crust, and it is thus that, as before mentioned, the crystalline schists are produced. The granite does not therefore, as Suess has supposed, fill great cavities in the earth's crust which have been produced by tangential stresses, thus giving rise to batholites, but starting from some line of fracture eats its way into the surrounding rocks and develops itself largely at their expense in the way above described.

According to Professor Duparc and his associates, this process of granitization plays a very important rôle in the development of the crystalline rocks of the Mont Blanc massiv. This massiv has usually been considered as composed of protogine, that is of a somewhat altered granite, massive in the center and progressively more gneissic or schistose as the outer portions are approached, the whole enveloped by a mantle of mica schists. These mica schists contain bands of amphibolite, eclogite, and other similar rocks found in corresponding positions about other protogine masses elsewhere in the Alps.

Messrs. Vallet and Duparc have however found that the central part of the massiv is composed largely of various micaceous gneisses and crystalline schists, associated with and invaded by the protogine and even passing into a protogine gneiss. Some of these included rocks

are very basic and cannot therefore, it is thought by the authors, be in any way considered to be derived from the protogine by dynamic action, but are to be considered as sediments, depressed by a synclinal fold and bounded by the protogine on either side. The whole series of rocks, both protogine and surrounding schists, are penetrated by a series of more recent granite veins or dykes, and these it is believed have brought about the profound metamorphism of the surrounding rocks, injecting and "granitizing the schists everywhere in the vicinity of the protogine, so that the gneissic zone which immediately borders the protogine is not in any way connected, genetically, with the protogine itself, but results from the profound alteration of the mica schists surrounding the protogine by these newer granite dykes. The varying character of the different schistose rocks in this gneissic zone is considered to be due to the varying resistance offered to this "granitizing" action by the different beds in question. Thus, for instance, the eclogites retain their basic character and have not been transformed into orthoclase gneiss, because they are too compact to allow of a free circulation through them of the solutions producing the alteration. In the paper by Duparc and Mrazec, a number of analyses of the several varieties of protogine and granitized schists are given.

The crystalline schists of eastern Sutherland, described by Messrs. Horne and Greenly, consist of a series of gneisses, granulites, mica schists, etc., some few members of which show conclusive evidence of a sedimentary origin while the origin of others is doubtful. The whole series has been intensely deformed. Not a cubic inch can be found which has not suffered deformation, but distinct cataclastic structure is not seen, so that recrystallization must have taken place during or after the movements. The series is invaded by masses of intrusive granite, which have broken across the schists, anastomozing through them and often penetrating them as a series of thin leaves, parallel to their foliation, in the manner termed by the French writers *lit par lit* injection. The boundary between the injecting granites and the schistose series is often rather ill-defined, owing to the fact that the granitic constituents seem to interlock with those of the wall rock with which they are in contact. The granite never shows any finer grained sahlband, indicating injection to a cold rock, but is usually coarse-grained and pegmatitic on the borders. It seems reasonable to infer, therefore, that the igneous material was introduced when earth movements were in progress and when the country rock was at a high temperature.

On approaching large masses of granite, the schistose series becomes more highly altered, sillimanite and other contact minerals making their appearance, but the invaded rocks often take upon themselves a character so closely resembling that of the invading granite as to "amalgamate the two rocks into one great gneissose complex." Thus the foliation of the invading granite, which can often be seen to be parallel to that of the invaded gneisses, is in many cases certainly due to the biotite foliæ of the latter, having retained their original position, while the associated "quartzo-feldspathic elements have been incorporated with those of the granite," as every gradation can be traced from inclusions retaining their natural orientation to the merest trains of mica flakes in a granitic rock. In other cases, however, the foliation of the invading granite does not coincide with that of the invaded gneiss but cuts it. Powerful movements were the "initial cause of the whole series of phenomena. . . . . With regard to the granites, it is difficult to believe that they are wholly foreign matter; though here it is necessary to observe the utmost caution, the chemical difficulties being so great." Although Messrs. Horne and Greenly are guarded in their statements, their studies being rather general in character, it is clear that they believe the processes at work to be very similar, if not identical with, those described by Michel-Lévy and Duparc.

The views put forward in these papers lead us back to the time of Hutton, who, in his *Theory of the Earth* states that the kind of granite which shows banding and foliation is probably an altered sediment, the foliation being a survival of the bedding of the original rock. This fact, however, does not by any means discredit the view as many of Hutton's opinions after long neglect have finally proved to be correct. The views also have certain features in common with the crenitic hypothesis of Hunt. The whole process is, however, very recondite and mysterious in character.

One of the great difficulties in the way of the acceptance of these views is the absence of chemical proof. In those contact zones on which accurate chemical work has been done, it has been shown that no considerable transference of material has taken place. In these other cases where this enormous transference of material is assumed, no accurate chemical work seems to have been carried out to support the contentions. In Duparc's work, as has been mentioned, a number of analyses of various normal and "granitized" rocks are given, but

no attempt is made to follow out the changes undergone by a single bed, and it is impossible to make out in how far the differences in composition shown to exist, are primary differences in the composition of the rocks analyzed. The chemical evidence adduced is, therefore, by no means conclusive. The question also arises as to the ultimate source of the enormous amounts of silica and alkalis required for the conversion of hundreds of cubic miles of the miscellaneous rocks of a sedimentary system into granite.

It is furthermore a question as to how far dynamic action is responsible for many of the phenomena described. When, for instance, a schist is shattered and granite is intruded into the cracks and fissures, masses of the invaded rock being found scattered through the granite, and, after cooling, the whole complex is stretched or rolled out by dynamic movements, as is usually the case in districts where crystalline schists occur, the injected arms of the granite, great and small, become pulled apart and eventually appear as little discontinuous strings and lumps of quartz and feldspar in the enclosing schists, following the line of movement, while a schistose structure parallel to these strings is given to the whole rock by the same movements.

In certain parts of the Laurentian of Canada, schists and gneisses are found full of such strings and lumps of quartz and feldspar, presenting exactly the characters described by the French petrographers as resulting from the granitization of sedimentary rocks. The Canadian rocks, however, have undoubtedly been produced in the way just described, every possible transition from the massive injection to the foliated complex being observed in a hundred different cases. In the Lepontine Alps, moreover, to the east of Mont Blanc, where the *Schieferhülle* of the several protogine masses have been very carefully studied by Heim, Schmidt, and many other observers, the phenomena attributed to "granitization" by Duparc are everywhere considered to be the results of crushing under the influence of such movements, with, in certain cases, the infiltration of secondary cracks and rifts by materials deposited from ordinary terrestrial waters, which in such positions would probably be more or less heated. Even in the Saxon Granulitgebirge, cited by Michel-Lévy as a case where transference of material could be distinctly observed, and where certainly the granulite does seem to have eaten its way into the schists, only however for a short distance back from the immediate contact, the appearance presented bearing a striking resemblance to that, very familiar to the tyro

in assaying, when his slag being too basic has eaten its way into the clay crucible appearing when the crucible is broken through its substance here and there in spots and streaks; Lehmann, who has made a most exhaustive study of the whole region points to the fact that this zone is not always present, and states it to be his belief that the granitic material forming the *flammen* in the schist has not been derived from the granulite magma, but is due to the deposition of the granitic material in spaces formed by the separation of the foliæ of the schist, under the great stresses to which the region has been subjected, the granitic material in question having been derived from later intrusions which elsewhere can be clearly seen to cut the granulite. From personal observation, however, I must say that appearances are strongly in favor of Naumann's view, that along the narrow zone of the immediate contact the granulite magma has eaten into the schist to a certain distance, a phenomenon which is quite intelligible and perhaps in certain cases to be expected, but which is quite distinct from the wholesale transformation of the schist into granite by the mysterious process of "granitization."

In how far this process of transfusion which is considered by Michel-Lévy and other French geologists to play so important a part in the origin of the crystalline schists is really active, must be determined by detailed studies of the deeper seated granite contacts and of the so-called Archean areas in various parts of the world.

Such studies in the case of Archean areas are presented in the recent maps, with accompanying explanatory texts, issued by the geological survey of Baden, and whose titles are given above. This survey, following the lead of those of Prussia, Saxony, and Hessen, was constituted in 1888 for the purpose of mapping in detail the Grand Duchy of Baden, an area of 5843 square miles, on a scale of $\frac{1}{25000}$. For this purpose the territory in question has been divided into 170 sections. Work was begun in 1889 and maps of twelve sections have already been published. As about one-quarter of the Grand Duchy of Baden is underlain by *Grundgebirge* including the well-known area of the Black Forest, ample opportunity is given for a thorough study of these ancient rocks. Six of the maps already published are in areas of the Grundgebirge; of these three have been mapped by Dr. Sauer, to whom we are already indebted for his valuable contributions to our knowledge of the ancient crystalline rocks of Saxony. The maps are among the best which have yet appeared of any Archean region, and serve to

bring out clearly the complex relations of the several members of the system.

Two distinct classes of gneissic rocks are recognized in the areas examined, in addition to the numerous intrusions of igneous rocks of various kinds. To each of these classes a collective name has been assigned, taken from a locality where it is well exposed; the first being known as the Rensch Gneiss and the second as the Schapbach Gneiss. A few of the most notable varieties of each class of rock are distinguished in mapping, but no attempt is made to map separately the bewilderingly numerous and minute petrographical variations of the gneissic rocks attempted in the survey of Saxony. The Rensch gneisses consist chiefly of orthoclase, biotite, and quartz. The mica is usually abundant, and sillimanite is a characteristic accessory constituent, often occurring as a paramorph after andalusite. Garnet and sphene are seldom found. The rock often shows in the arrangement of the constituents a structure similar to that seen in the hornstones of contact zones. The presence of small lenticular segregations of quartz, or of quartz and orthoclase, scattered through the rock is also a characteristic feature of the gneisses of this class. Conformably interbanded with these Rensch gneisses are subordinate masses of quartz schist, graphitoid schists and gneisses, pyroxene gneisses and amphibolites.

The Schapbach gneisses are much more uniform in character, usually poorer in mica, and have a marked tendency to assume a granitic aspect, often passing over into granulites. Quartz lenses and fine-grained, highly quartzose bands are absent, but garnet and orthite are frequently present. The only inclusions found in the gneisses of this class consist of a gabbro-like amphibolite. The gneisses of the two classes sometimes seem to pass into one another along the contacts, but the distinction is usually sufficiently well marked to enable them to be properly separated in mapping.

Although no direct expression of opinion concerning the origin of these gneisses is given in the publications in question, it seems to be the opinion of the survey that the two classes probably differ in origin, the Rensch gneisses representing highly altered sediments and the Schapbach gneisses being of igneous origin. The chemical evidence afforded by a number of analyses of typical gneisses of each series which are given, tend to support this view as does also the structure of the rocks, and the character of the subordinate intercalated masses in

the case of the Rensch Gneiss. The evidence one way or the other will, however, be greatly extended as the mapping with concomitant chemical investigation progresses, and the Director of the survey, Professor Rosenbusch, evidently desires to await this further evidence before making any decided statements concerning the genetic relationships of the complex. If the Rensch gneisses prove to be altered sedimentary rocks their high content of feldspar and the presence in them everywhere of lenticular masses and strings of quartz and feldspar will certainly be cited by the French authorities as evidences of "granitization." But two questions remain to be decided — first, whether the high content in feldspar is not due to a high content of alkalis in the original sedimentary rocks, these having been perhaps of the nature of feldspathic sandstones, arkoses and greywackes, and secondly, whether the strings and lenses of quartz or quartz and feldspar do not fill spaces opened by the dynamic movements to which the rocks have been subjected, quite independent of any granitic intrusion. Whether in fact any mysterious cementation-like transfusion of granitic material through these rocks has really taken place. The detailed chemical work which is now being carried out will, when completed, undoubtedly decide whether the supposed altered sediments have or have not a composition which can be attributed to a sedimentary series.

A similar twofold origin is claimed by Klemm for the crystalline Grundebirge of the Spessart, although here the sedimentary portion is believed to be of late Palæozoic age and is possibly equivalent to a series of schistose hornstones, graphite schists and garnet rocks, quite distinct from the gneissic series of the Black Forest, which were found by Andreæ and Osann in the Odenwald to the north of Heidelberg.

These studies bearing upon the vexed question of the origin of the crystalline schists have at present an especial interest for petrographers in America, where such enormous areas of these rocks are now under investigation. FRANK D. ADAMS.

Glaciers of North America, a Reading Lesson for Students in Geography and Geology. By ISRAEL C. RUSSELL. Boston: Ginn & Co., 1897.

The preparation of a work of this high grade by a busy university professor of large professional experience and demonstrated investigative ability, as a reading lesson for students of geography and